Results from BNL E949 on $K^+ \to \pi^+\gamma\gamma$

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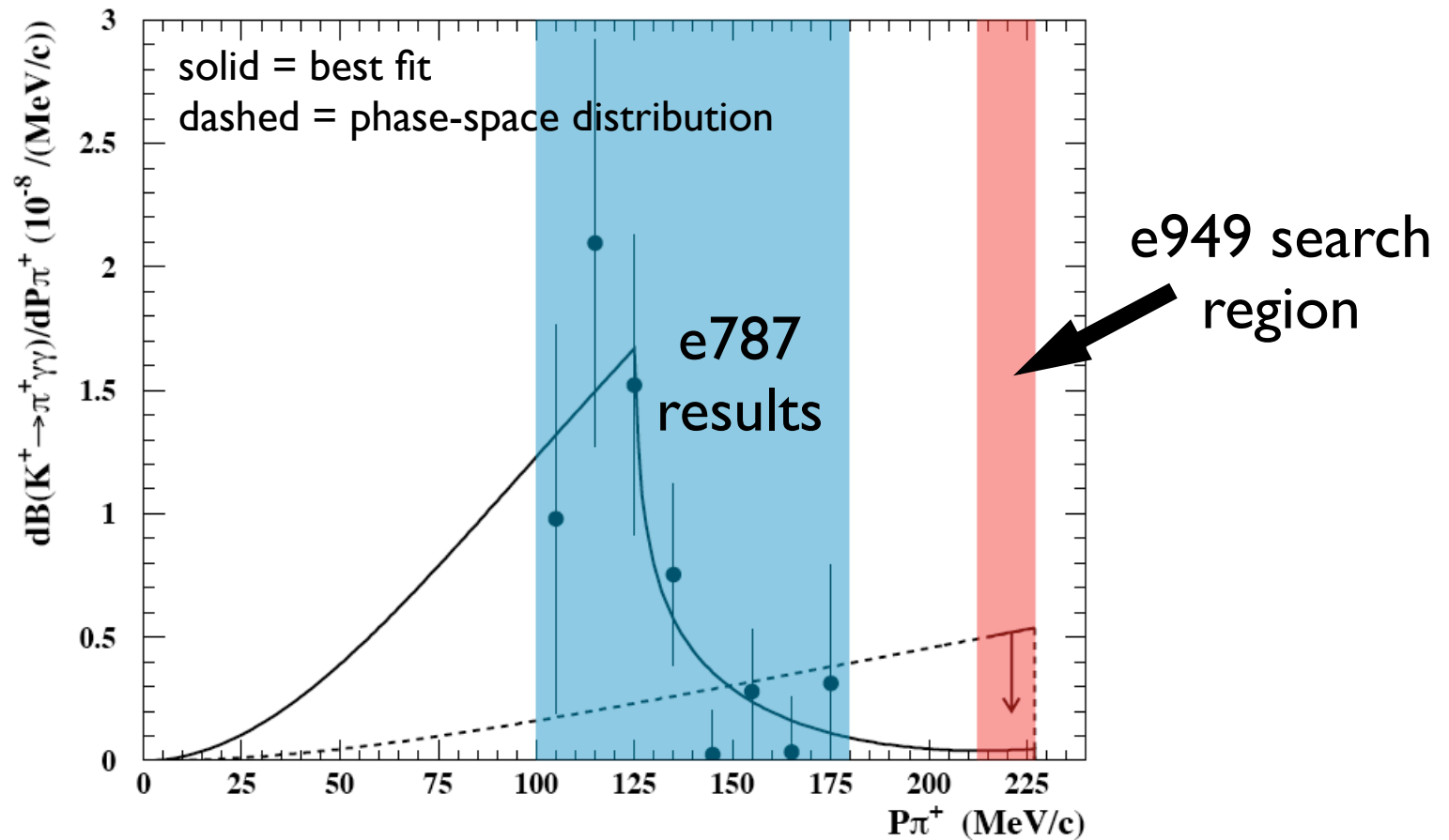T. Numao, J.-M. Poutissou and R. Poutissou
TRIUMF

π^+ Momentum Spectrum for E787

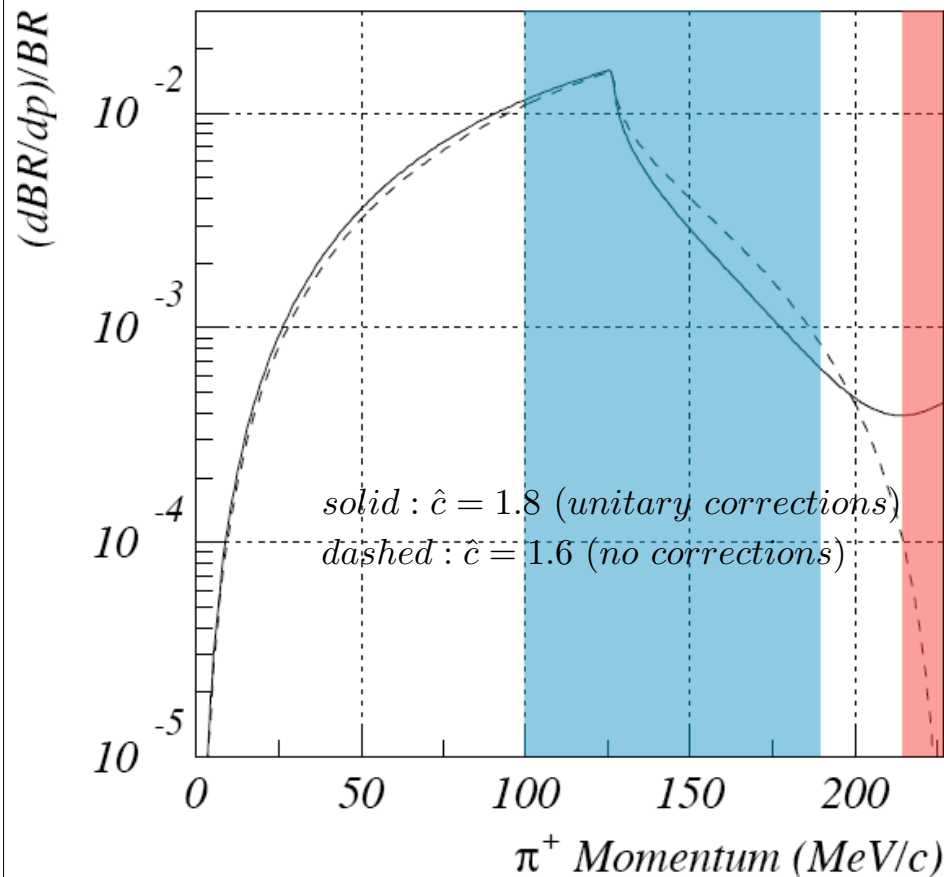$Below\ K^+ \to \pi^+\pi^0\ peak$ $\mathcal{B}(K^+ \to \pi^+\gamma\gamma) = [6.0 \pm 1.5 \pm 0.7] \times 10^{-7}$

$Above\ K^+ \to \pi^+\pi^0\ peak$ $\mathcal{B}(K^+ \to \pi^+\gamma\gamma)\ <\ 5.0 \times 10^{-7}$

P. Kitching *et al.*, Phys. Rev. Lett. **79**, 4079 (1997).

Branching Ratio from ChPT

solid : $\hat{c} = 1.8$ (unitary corrections)
dashed : $\hat{c} = 1.6$ (no corrections)

π^+ Momentum (MeV/c)

y-axis: $(dBR/dp)/BR$

- $O(p^6)$ corrections increase BR by 30-40%.

- Finite BR at kinematic end point.

Values obtain from E787 1991

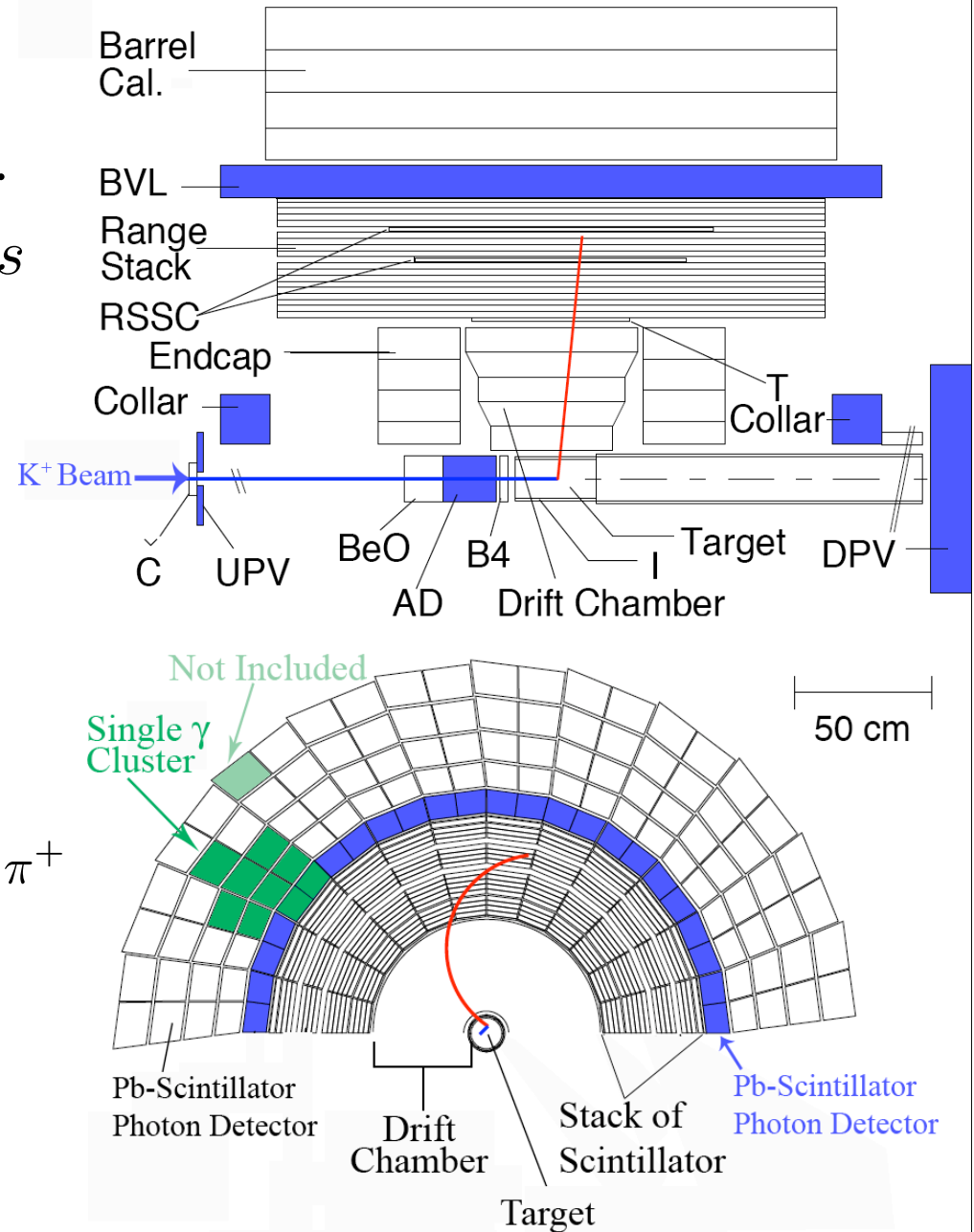$$\hat{c}_{O(p^4)} = 1.6 \Longrightarrow \mathcal{B} = 4.9 \times 10^{-10}$$
$$\hat{c}_{O(p^6)} = 1.8 \Longrightarrow \mathcal{B} = 6.1 \times 10^{-9}$$
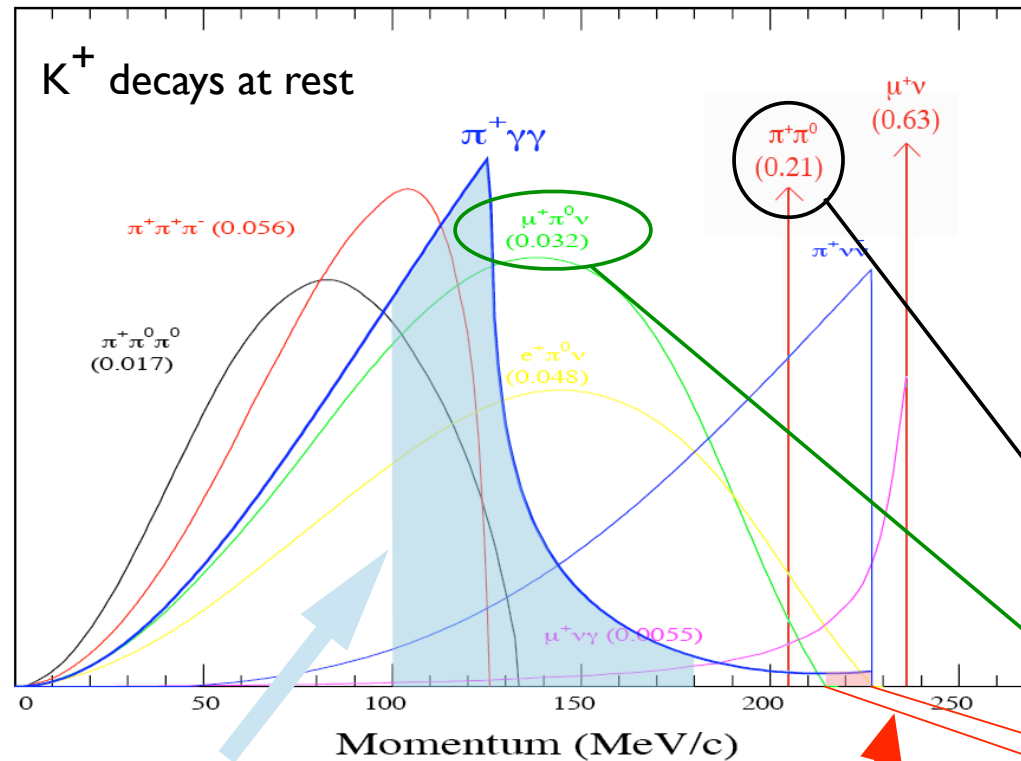
Order of Magnitude different!

E949 Detector & Trigger

- K^+ *enters detector & stops.*
- K^+ *decays : detect π^+ and γs*

Barrel Cal.

BVL

Range Stack

RSSC

Endcap

Collar

K^+ Beam

C UPV

BeO B4

AD Drift Chamber

T Collar

Target DPV

I

- *Trigger on 1 or 2 γ clusters*
  - *γ in Barrel photon detectors*
  - *$2\gamma \rightarrow 1$ γcluster for high mom. π^+*

- *long range π^+*

Not Included

Single γ Cluster

50 cm

Pb-Scintillator Photon Detector

Drift Chamber

Stack of Scintillator

Target

Pb-Scintillator Photon Detector

Backgrounds & Trigger Events

K^+ decays at rest

$\pi^+\gamma\gamma$

$\pi^+\pi^+\pi^-$ (0.056)

$\mu^+\pi^0\nu$ (0.032)

$\pi^+\pi^0$ (0.21)

$\mu^+\nu$ (0.63)

$\pi^+\pi^0\pi^0$ (0.017)

$e^+\pi^0\nu$ (0.048)

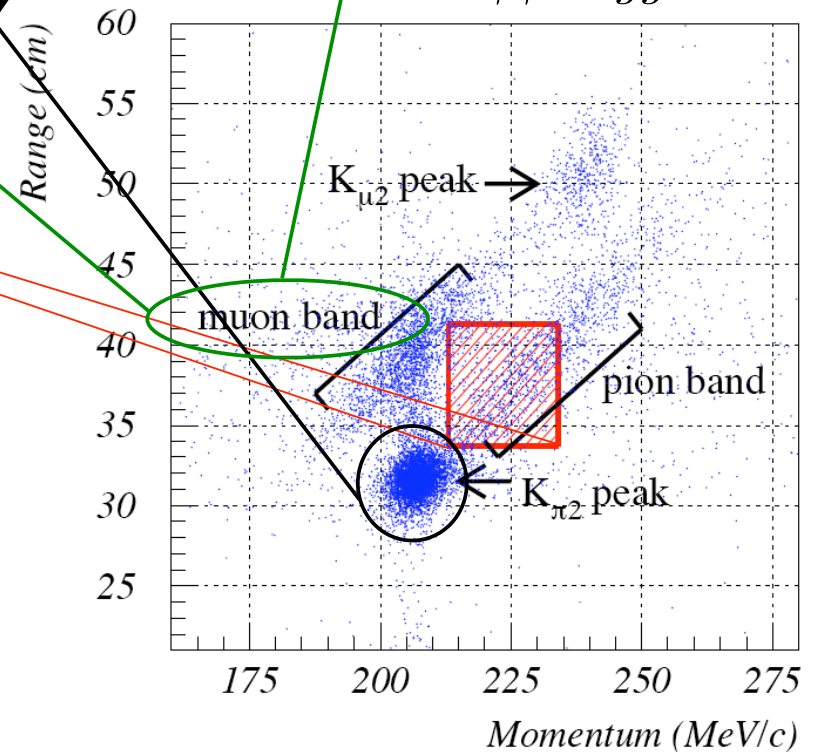$\pi^+\nu\bar{\nu}$

$\mu^+\nu\gamma$ (0.0055)

Momentum (MeV/c)

E787 Signal Region

E949 Signal Region

$$K^+ \to \pi^+\pi^0; \pi^0 \to \gamma\gamma$$
SAME FINAL STATE!

Background from $K^+ \to \pi^+\pi^0$

$$K^+ \to \mu^+\nu\gamma$$
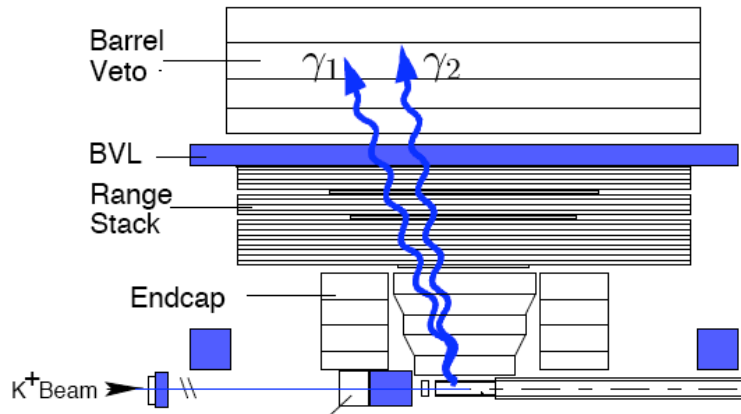$$K^+ \to \mu^+\pi^0\nu$$

$K^+ \to \pi^+\gamma\gamma$ triggers

Range (cm)

$K_{\mu2}$ peak →

muon band

pion band

$K_{\pi2}$ peak

Momentum (MeV/c)
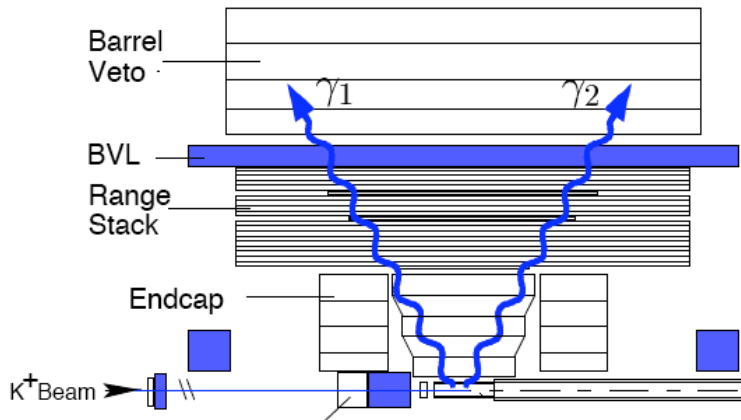
$K^+ \to \pi^+\pi^0$ Background
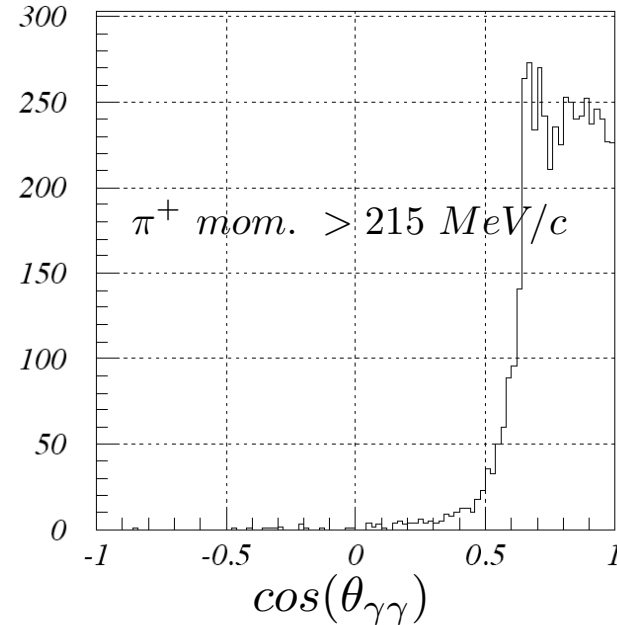
$K^+ \to \pi^+\gamma\gamma$ signal

background from $K^+ \to \pi^+\pi^0$

Suppress backgrounds

- $Use\ \pi^+\ kinematics$
- $Opening\ angle\ cut\ on\ \gamma s$

Overlapping γ Background

$$K^+ \to \pi^+ \pi^0$$

π^+ Track

Low Energy Photon

High Energy Photon
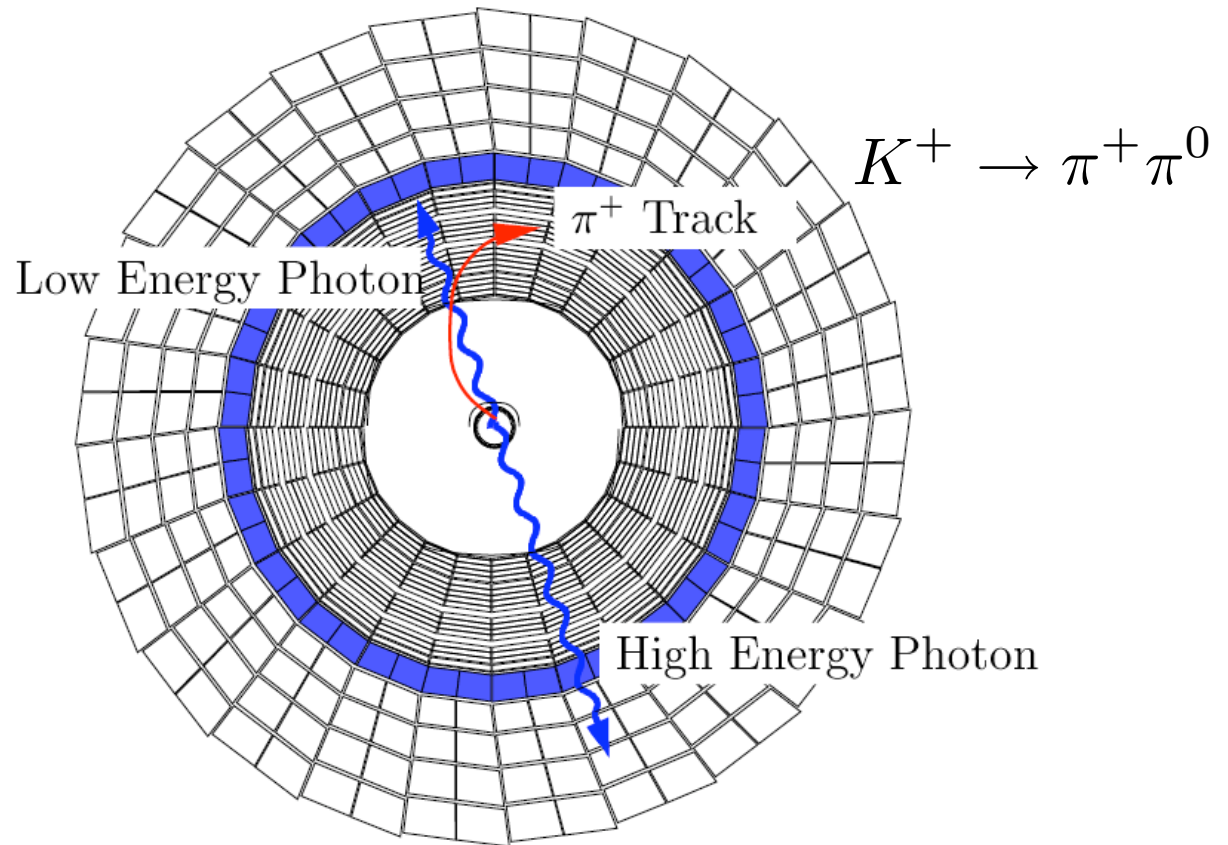
- *Cut on overlapping γ by observing larger than expected energy*

Results

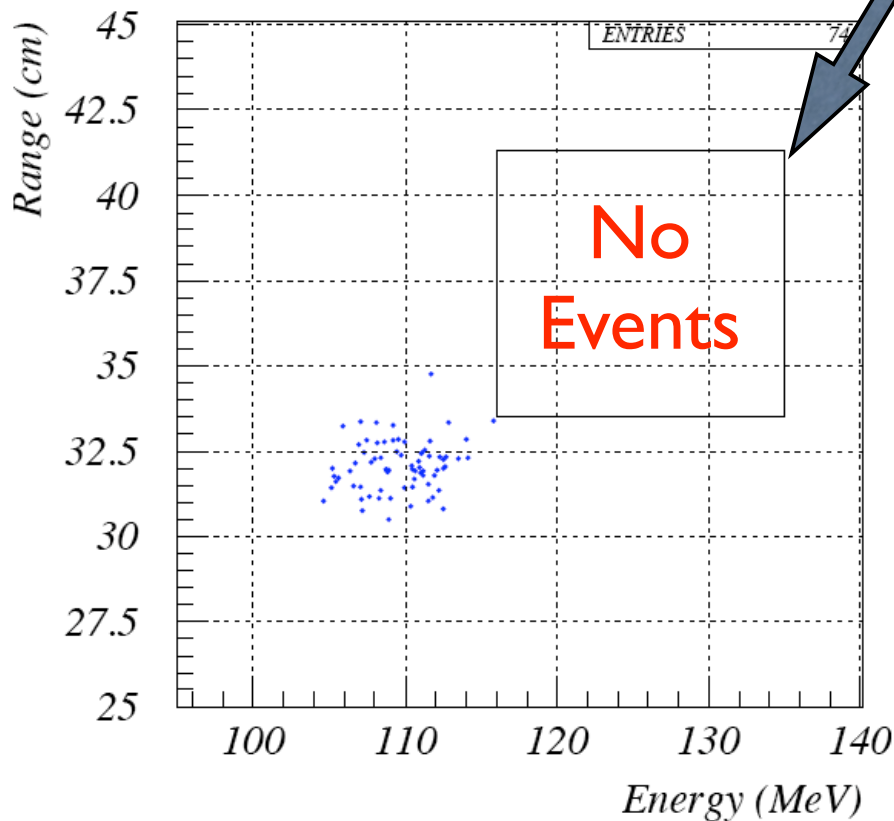| Background	Background level
$K^+ \rightarrow \pi^+ \pi^0$	0.017 ± 0.006
Overlapping γ	0.065 ± 0.065
Muon	0.090 ± 0.020
Single Beam	0.025 ± 0.014
Double Beam	$0.006\ (90\%\ C.L.)$
Total	0.197 ± 0.070

Acceptance

$$A_{O(p^6)}^{\pi^+ \gamma\gamma} = 1.550 \pm 0.034 \times 10^{-4}$$
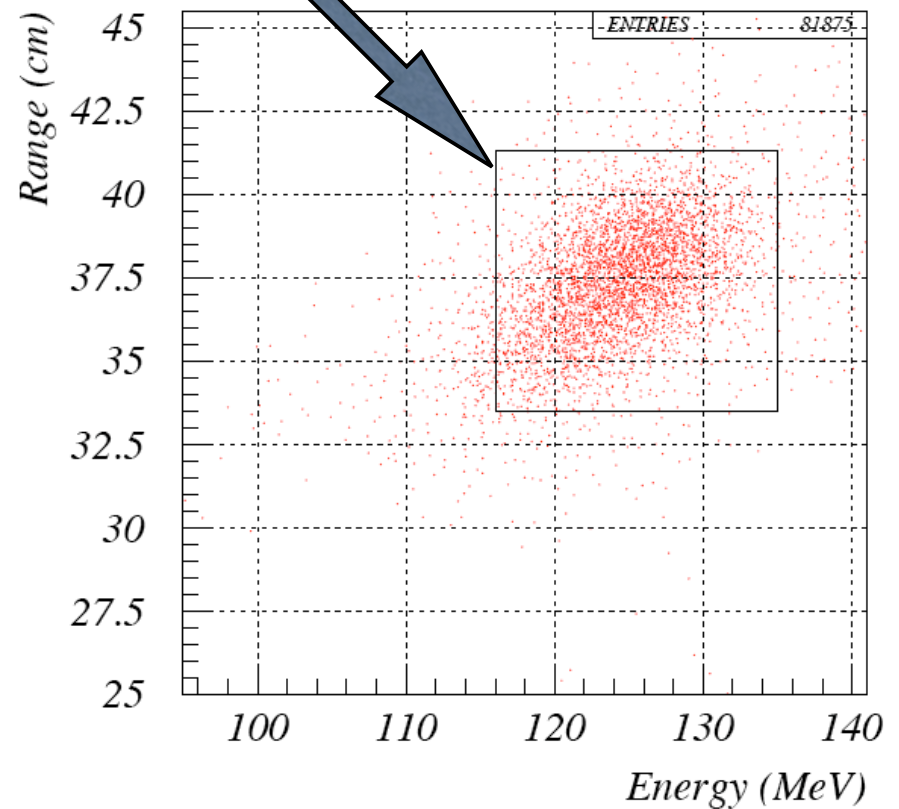
Expected Number of Events

$$\boxed{1.6}$$
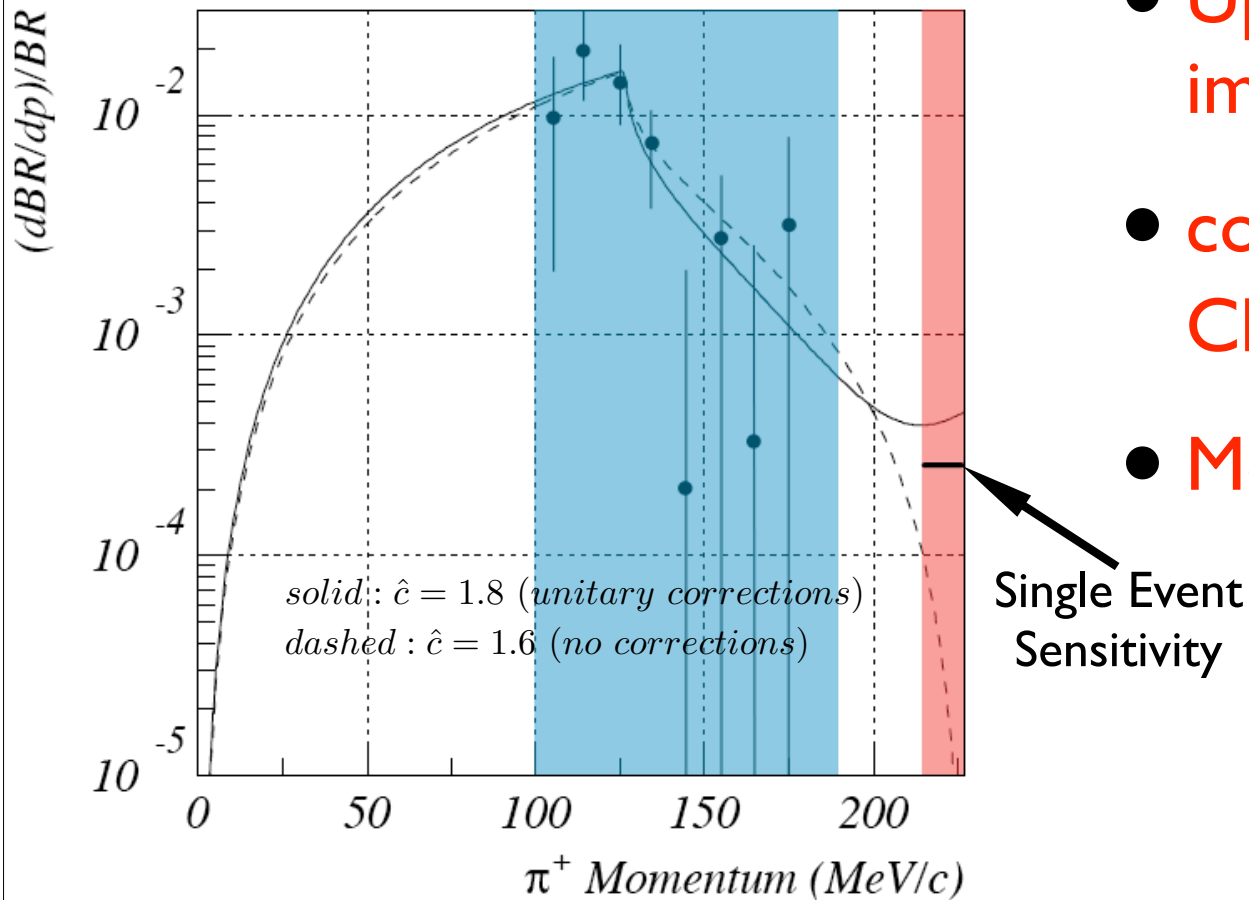
Open Box

$$K^+ \to \pi^+ \gamma\gamma$$
Signal Region

Surviving events
All cuts applied

Simulated distribution
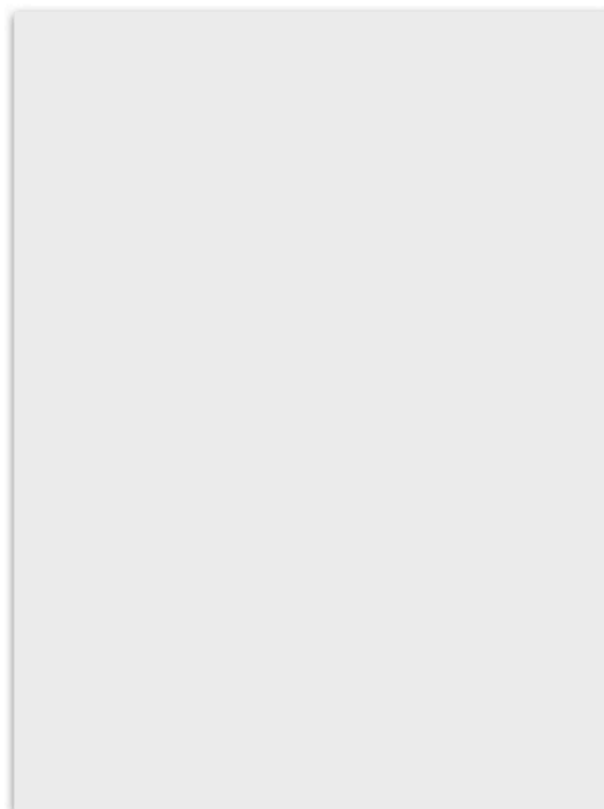$\hat{c} = 1.8$ unitarity corrections

Conclusions

$$\mathcal{B}(K^+ \to \pi^+ \gamma\gamma; P_{\pi^+} > 213 MeV/c) \ < \ 9.1 \times 10^{-9} \ \ (90\% \ CL)$$

solid : $\hat{c} = 1.8$ (unitary corrections)
dashed : $\hat{c} = 1.6$ (no corrections)

Single Event
Sensitivity

- Upper limit 7.6x improvement
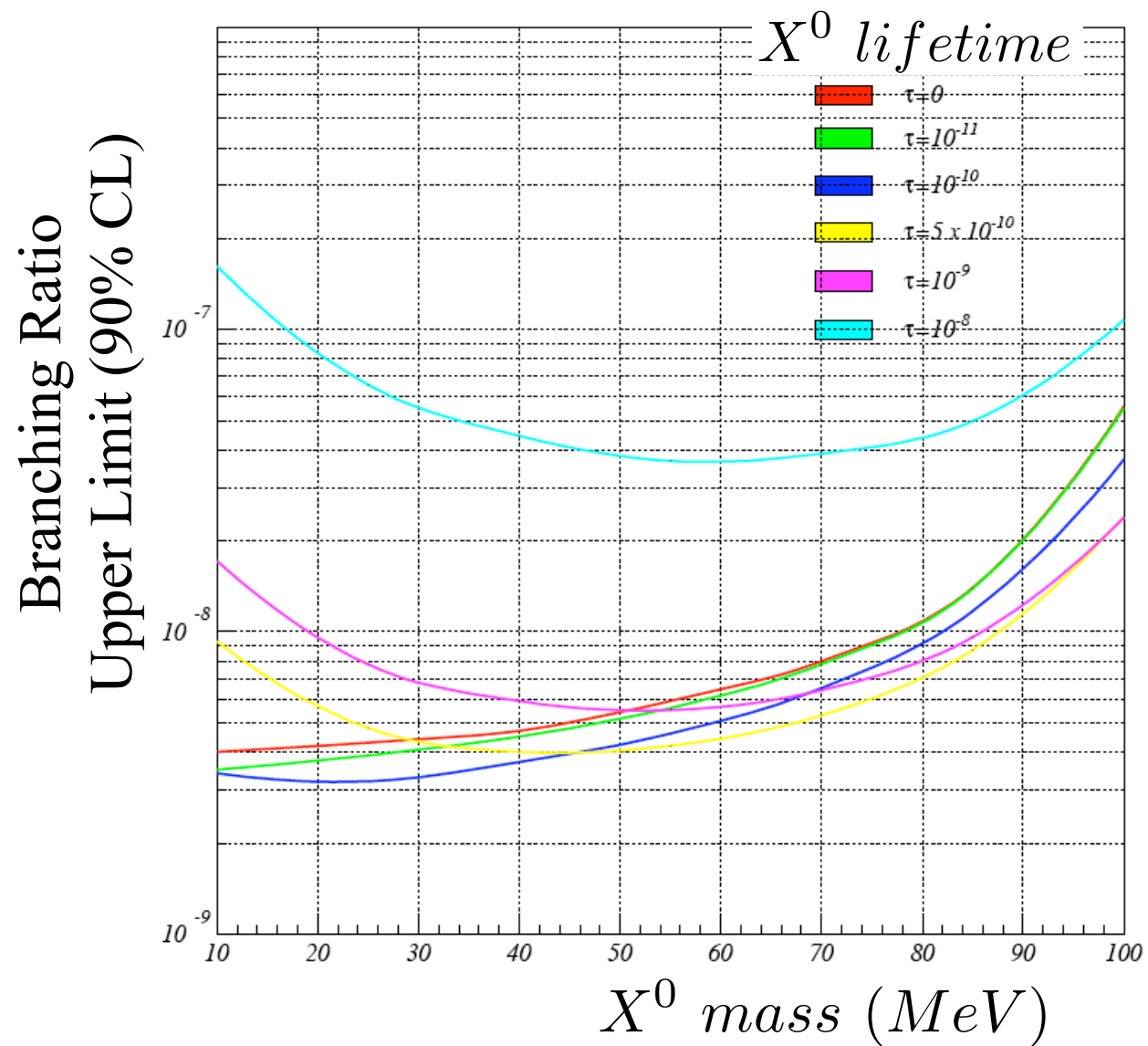
- consistent with ChPT $O(p^6)$ & $O(p^4)$

- More data needed.

THANK YOU

- Upper

Extras

$K^+ \to \pi^+ X^0, X^0 \to \gamma\gamma$
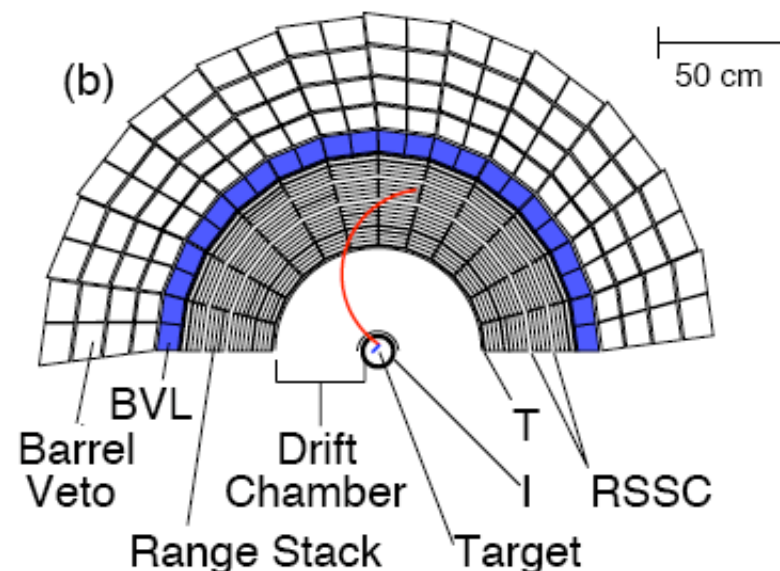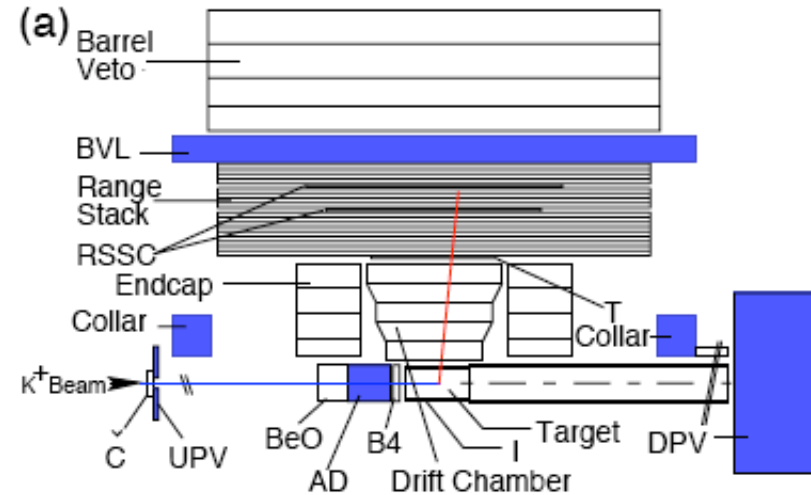
E949 Method

K^+ enters E949 Detector

- Cerenkov: K^+/π^+ (PID)
- Active Degrader: slows K^+
- Target: K^+ comes to rest.
- Beam: no other particles (PID)

K^+ decays

- Target: 'Delayed Coincidence' between K^+ and π^+ (Timing)
- Photo Veto: extra E (Veto)
- Target: E,R,T (Kinematics)
- Drift Chamber: P (Kinematics)
- Range Stack: E,R (Kinematics)

π^+ decays

- Range Stack:
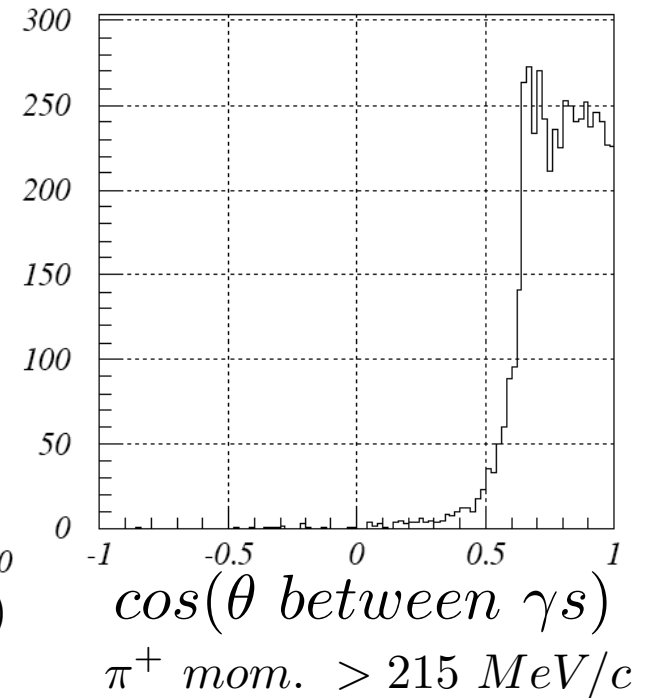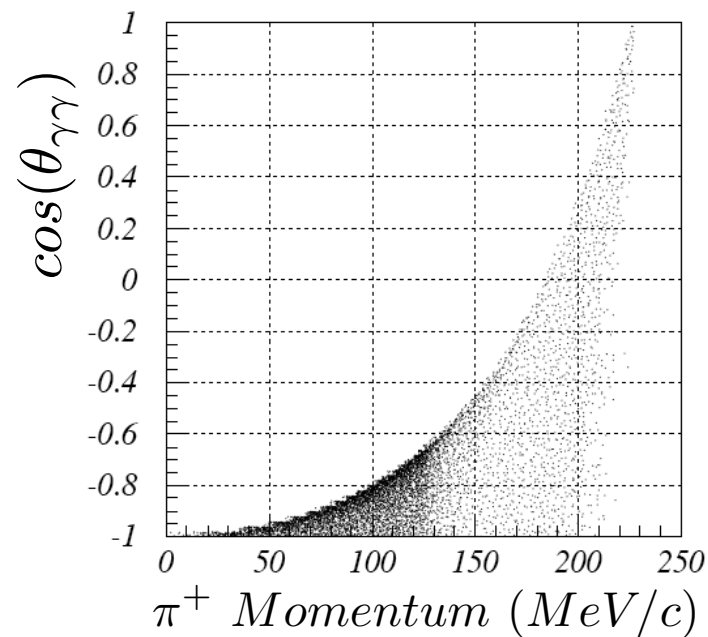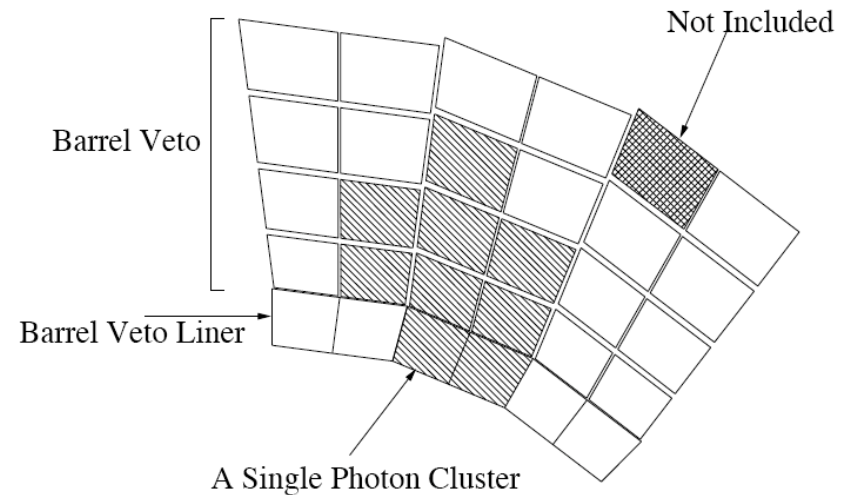 $$\pi^+ \to \mu^+ \to e^+ \text{ (PID)}$$

(a)

Barrel Veto
BVL
Range Stack
RSSC
Endcap
Collar
K^+Beam
C   UPV
BeO   B4
AD   Drift Chamber
I   Target
Collar
T
DPV

(b)

50 cm

BVL
Barrel Veto
Drift Chamber
Range Stack
I
Target
T
RSSC
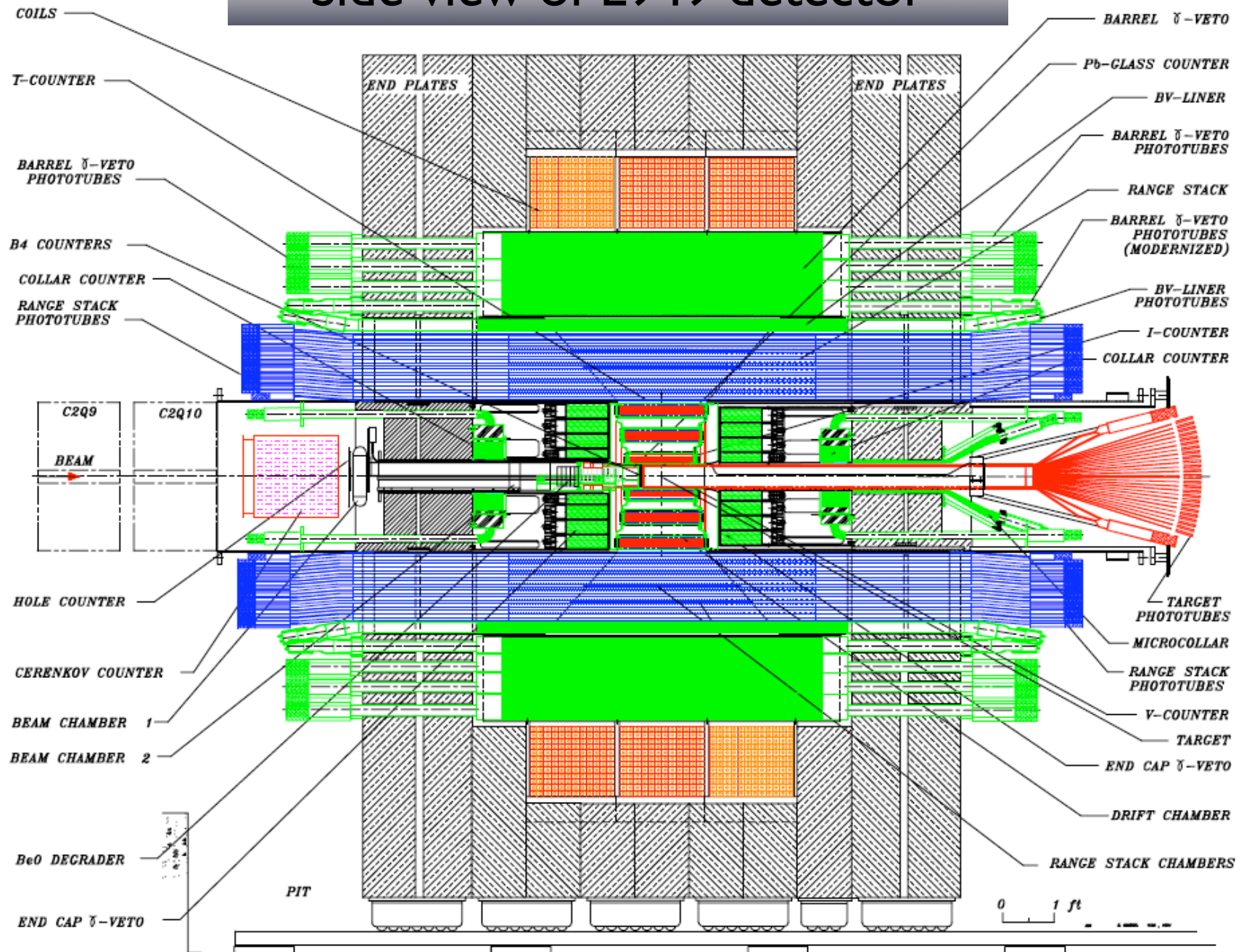
Reconstructing Photons in BV & BVL

- *Trigger on 1 or 2 γ clusters*

- *2 $\gamma \rightarrow$ 1 $\gamma cluster$*
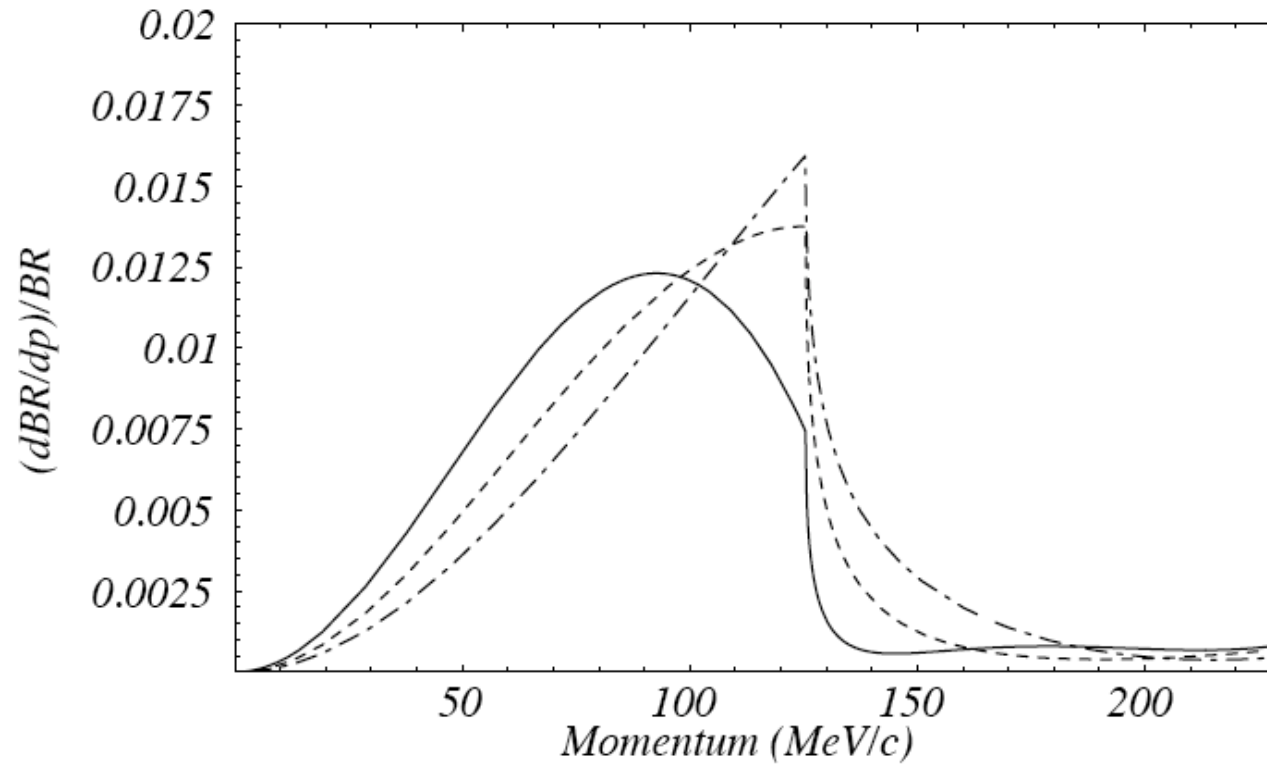 *for high mom. π^+*

Barrel Veto

Not Included

Barrel Veto Liner

A Single Photon Cluster

Signature of Signal

$cos(\theta_{\gamma\gamma})$

π^+ *Momentum (MeV/c)*

$cos(\theta$ *between* $\gamma s)$

π^+ *mom. > 215 MeV/c*

Side view of E949 detector

COILS

T-COUNTER

BARREL ɣ-VETO PHOTOTUBES

B4 COUNTERS

COLLAR COUNTER

RANGE STACK PHOTOTUBES

HOLE COUNTER

CERENKOV COUNTER

BEAM CHAMBER 1

BEAM CHAMBER 2

BeO DEGRADER

END CAP ɣ-VETO

END PLATES

END PLATES

C2Q9

C2Q10

BEAM

PIT

BARREL ɣ-VETO

Pb-GLASS COUNTER

BV-LINER

BARREL ɣ-VETO PHOTOTUBES

RANGE STACK

BARREL ɣ-VETO PHOTOTUBES (MODERNIZED)

BV-LINER PHOTOTUBES

I-COUNTER

COLLAR COUNTER

TARGET PHOTOTUBES

MICROCOLLAR

RANGE STACK PHOTOTUBES

V-COUNTER

TARGET

END CAP ɣ-VETO

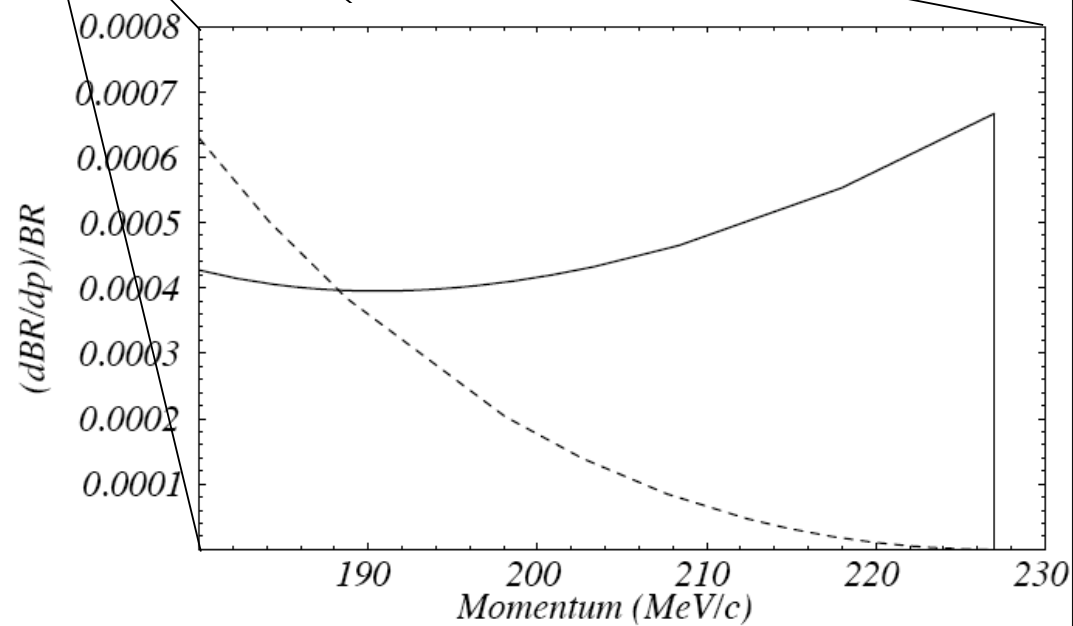DRIFT CHAMBER
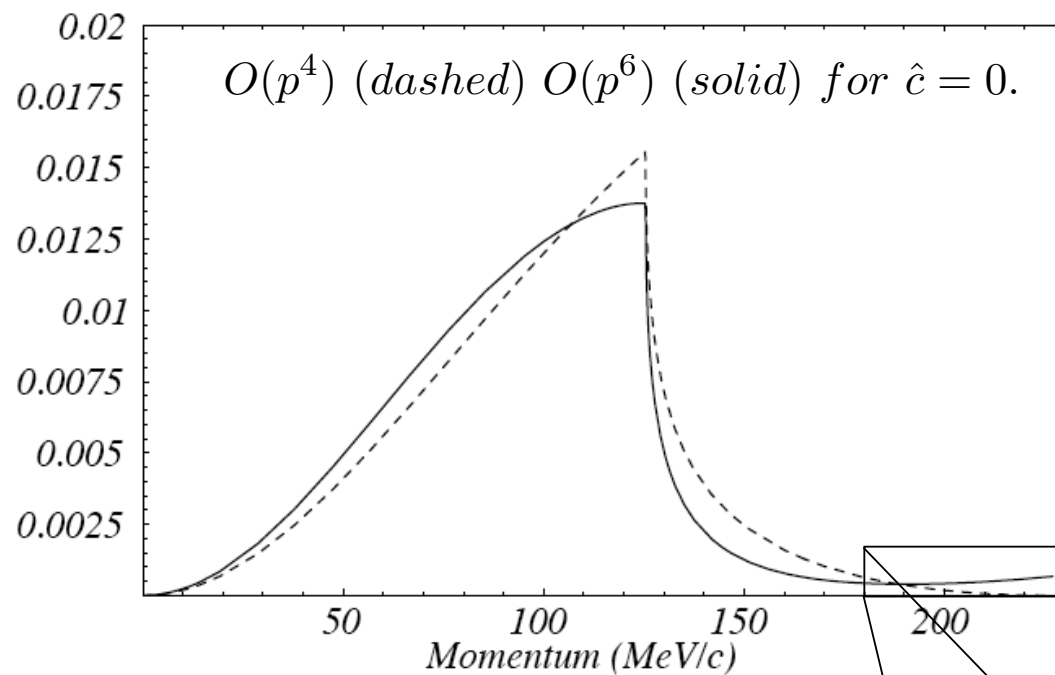
RANGE STACK CHAMBERS

0   1 ft

Differential Branching Ratio

$$ChPT \ with \ O(p^4)$$

$\hat{c} = -2 \ (solid), \hat{c} = 0 \ (dashed), \hat{c} = 2 \ (dot-dashed)$

π^+ Momentum Spectrum

$O(p^4)$ (dashed) $O(p^6)$ (solid) for $\hat{c} = 0.$

Momentum (MeV/c)

(dBR/dp)/BR

Momentum (MeV/c)

Branching Ratio from ChPT
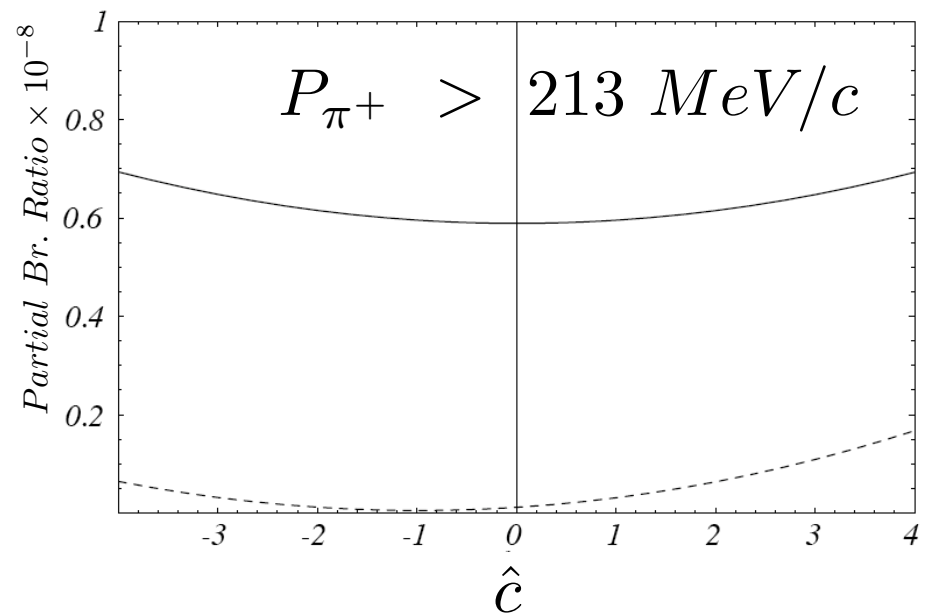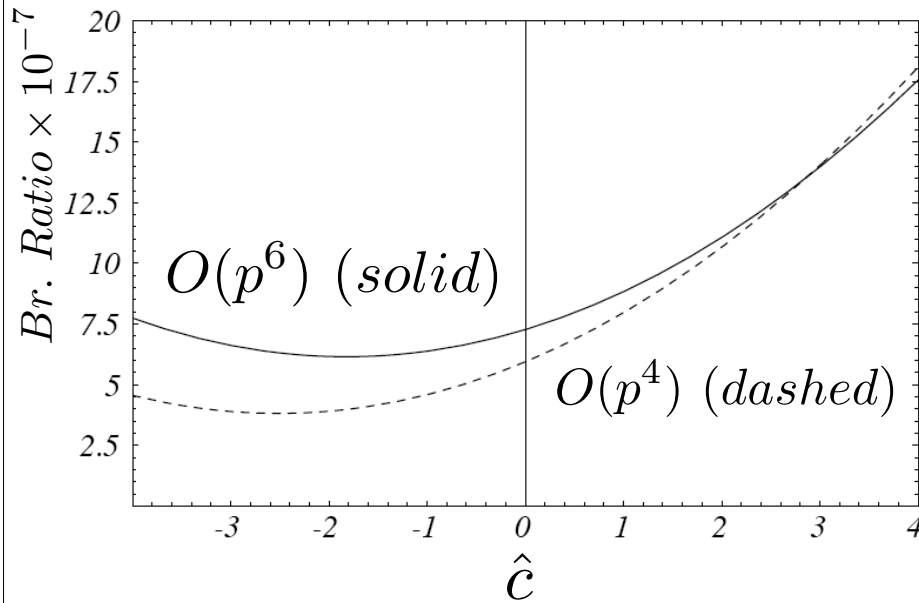
Values obtain from E787 1991

$$\hat{c}_{O(p^4)} = 1.6 \implies \mathcal{B} = 4.9 \times 10^{-10}$$
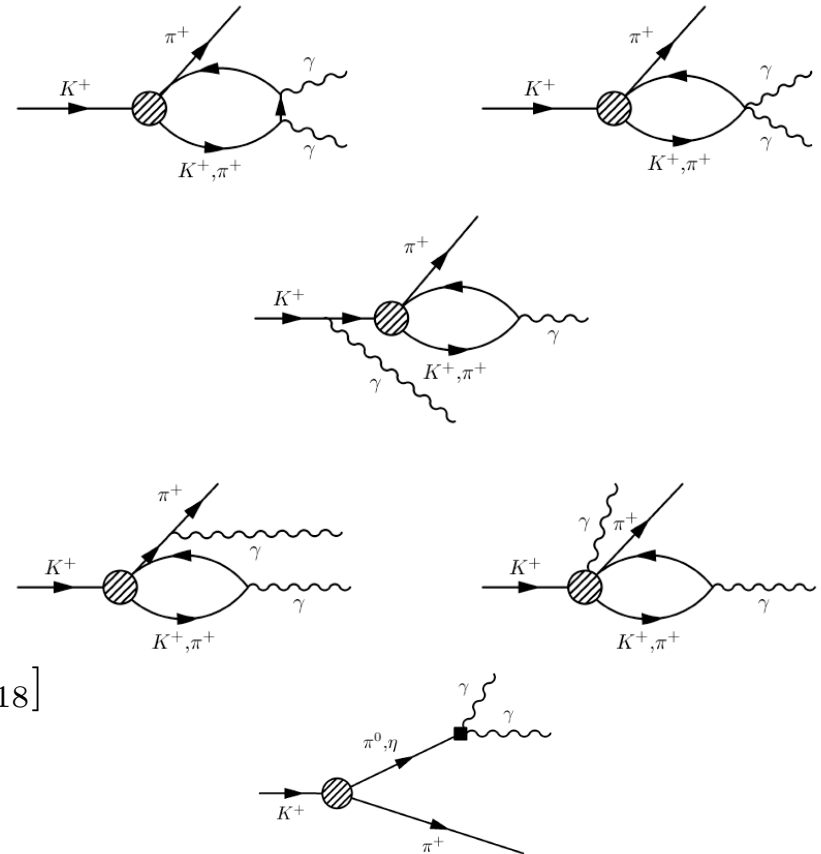$$\hat{c}_{O(p^6)} = 1.8 \implies \mathcal{B} = 6.1 \times 10^{-9}$$

Order of Magnitude different!

Chiral Perturbation Theory (ChPT)

ChPT prediction for $K^+ \to \pi^+ \gamma\gamma$

loop diagrams from ChPT for $\mathcal{O}(p^4)$

- no tree level contribution $\mathcal{O}(p^2)$

- $K^+ \to \pi^+ \gamma\gamma$ amplitude is determined by $\hat{c}$

- $\hat{c} \equiv \dfrac{128\pi^2}{3}[3(L_9 + L_{10}) + L_{14} - L_{15} - 2L_{18}]$

Backgrounds & Trigger Events

K^+ decays at rest

$\pi^+\gamma\gamma$

$\mu^+\nu$ (0.63)

$\pi^+\pi^0$ (0.21)

$\pi^+\pi^+\pi^-$ (0.056)

$\mu^+\pi^0\nu$ (0.032)

$\pi^+\nu\bar{\nu}$

$\pi^+\pi^0\pi^0$ (0.017)

$e^+\pi^0\nu$ (0.048)

$\mu^+\nu\gamma$ (0.0055)

Momentum (MeV/c)

$K^+ \to \pi^+\gamma\gamma$ triggers

Range (cm)

$K_{\mu2}$ peak

muon band

pion band

$K_{\pi2}$ peak

Momentum (MeV/c)

Backgrounds	Suppression Methods			
	Kinematics	Photon	Particle ID	Timing
$K^+ \to \pi^+\pi^0$	✓	✓		
Overlapping Photon	✓		✓	
Muon	✓		✓	
Single Beam			✓	✓
Double Beam				✓✓

Backgrounds	Suppression Methods			
	Kinematics	Photon	Particle ID	Timing
$K^+ \to \pi^+ \pi^0$	√	√		
Overlapping Photon	√		√	
Muon	√		√	
Single Beam			√	√
Double Beam				√√